ANALYTICAL ELECTRON MICROSCOPY OF FINE-GRAINED PHASES IN PRIMITIVE INTERPLANETARY DUST PARTICLES AND CARBONACEOUS CHONDRITES.

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Exploration of the Solar System by spacecraft over the past few decades has not only provided an enhanced appreciation of the geological diversity within planetary bodies, but also a greater understanding of the origin and evolution of our Solar System and perhaps others within the galaxy. A fundamental component of this understanding involves the compilation and analysis of chemical, physical and mineralogical data on the smaller bodies within the Solar System. These bodies (or their fragments) probably contain a record of processes occurring early in the evolution of the Solar System. In general, the fine-grained fractions (i.e. <1 μm) of solid materials in primitive meteorites and micrometeorites are the most likely hosts for this record of early Solar System processes [1]. Any study of early Solar System processes should involve (a) characterization of known extraterrestrial materials intersecting Earth orbit [2,3], (b) an understanding of possible contaminants both in low Earth orbit and the upper atmosphere [4,5], (c) experimental verification of basic phenomena occurring in a stellar environment [6] and (d) the production of realistic models on aspects of Solar System evolution [1,7]. In the current phase of this research program, all approaches have been utilized and highlights of this work are given below.

In order to describe the total mineralogical diversity within primitive extraterrestrial materials, individual interplanetary dust particles (IDP's) collected from the stratosphere as part of the JSC Cosmic Dust Curatorial Program [8] have been analysed using a variety of AEM techniques. Identification of over 250 individual grains within one chondritic porous (CP) IDP shows that most phases could be formed by low temperature processes [2] and that heating of the IDP during atmospheric entry is minimal and less than 600°C [2, 9]. This observation agrees with more recent entry temperature estimates based upon solar flare track data. We have suggested that layer silicates observed in these IDP's could have formed by low temperature (cryogenic) alteration of precursor silicates [2]. In a review of the mineralogy of IDP's [1], we also suggest that the occurrence of other silicates such as enstatite whiskers is consistent with formation in an early turbulent period of the solar nebula during which C/O and Mg/Si ratios enhance condensation at temperatures <1000°C.

Considerable attention has been paid to carbon-rich phases in IDP's and at least three different forms have been identified [1]. Earlier work on poorly-graphitised carbons (PGC's) has shown that the basal spacing of synthetically-formed PGC varies with formation temperature [10]. This structure-temperature relationship has been proposed as a new type of cosmothermometer for primitive extraterrestrial materials [11]. This temperature dependence has been confirmed for naturally occurring PGC's in terrestrial environments [11,12]. The lower graphitisation temperatures predicted for carbonaceous chondrite and IDP PGC's also reflects the presence of catalysts during the graphitisation process [11]. Use of this cosmothermometer on observations of PGC's in carbonaceous chondrites or IDP's [11,12] provides a record of the last temperature event experienced by the

host body. Other types of carbon observed in IDP's include the polymorph carbon-2H, and we propose that this type of carbon formed by hydrous pyrolysis of precursor hydrocarbons [14]. A collaborative laser microprobe study on carbon-rich IDP's, previously characterized by AEM, provides inconclusive results on the presence of interstellar carbon [15] though they are consistent with previous ion microprobe studies.

Micrometeorites captured in low Earth orbit have also allowed a fortuitous calibration of orbital capture techniques for future dedicated Shuttle or Space Station missions [16]. Components returned from the Solar Maximum satellite have been exposed to space for about four years and thus, contain a continuous record of the local micrometeorite and debris environment by way of impact features (i.e. craters and penetration holes) with associated projectile residues and adhered solids [3]. Electron optical analyses of the returned Solar Max surfaces show that solid residue from the projectiles survived impact due, in part to the multi-layer design of thermal blankets and the variable approach velocities of impacting bodies [17]. Analysis of solid particles associated with impact features readily allows the identification of orbital debris, such as paint particles [16], as well as at least two types of micrometeorites: Mg-Fe silicates and Fe-Ni sulphides [3,16]. Detailed AEM observations on Mg-Fe silicate particles show that (a) they are Mg-rich olivines with a chemical signature similar to olivine in CM chondrites and (b) these olivines did not melt upon impact and survived impact without appreciable shock metamorphic effects, such as lattice distortion [18]. These observations provide an important database for the capture of pristine micrometeorites by Earth-orbiting capture cells or comet coma dust sampling devices [16,17].

Experimental confirmation of fundamental chemical and physical processes in a stellar environment, such as vapor phase condensation, nucleation, and growth by annealing, is an important aspect of astrophysical models for the evolution of the Solar System. For example, the microstructural development of refractory smokes can provide significant constraints on the kinetics of particle growth and accumulation in a stellar environment. Characterization of laboratory-produced smokes has shown that both infra-red spectroscopy and X-ray diffraction fail to detect the very initial stages of crystallite development during high temperature annealing of "amorphous" smokes [6]. Detailed AEM study indicates that microcrystallites of forsterite may directly condense from an MgO-SiO vapor phase system or form metastably shortly after condensation [6]. With annealing, both compositional and structural transformations of the MgO-SiO smokes occur and have been documented using the AEM [6]. Similar textural and structural observations have been presented for the ultra fine-grained minerals in four anhydrous chondritic IDP's, and are interpreted as evidence for annealing in the early history of the Solar System [15,19,20,25].

An inherent limitation of terrestrial-based laboratory experiments on particle condensation, nucleation and growth from a vapor phase is the influence of the Earth's gravity during smoke production. To overcome this experimental limitation, suggestions on the development of a particle (or "dust") facility on board the Shuttle, and ultimately, upon the Space Station have been proposed [21,22]. This potentially rich area for experimental confirmation of fundamental astrophysical concepts has also received attention with respect to understanding solar nebula physico-chemical processes such as turbulence and particle aggregation [23,24].

On a larger scale, the possible relationships between chondritic IDP's and chondrite meteorite components have also been investigated [1,25]. In one case, there may be mineralogical similarities between an IDP and the matrices of CO/CV chondrites or unmetamorphosed unequilibrated ordinary chondrites [25]. However, in general, a detailed comparison of chondritic IDP and carbonaceous chondrite mineralogies shows significant differences between the types of silicate minerals as well as the predominant oxides [1]. In a continuing effort to characterize the fine-grained matrix of carbonaceous chondrites, detailed structural and morphological studies of the mineral tochilinite have been presented [26]. This work arises from the suggestion that the commonly-known "poorly-characterized-phases" (PCP's) can in fact be identified as members of the mixed-layer tochilinite mineral group or as coherent intergrowths of tochilinite and serpentine [27]. This is a critical observation for models of CM matrix formation as tochilinite paragenesis, though incompletely studied, appears restricted to very specific environments on Earth [28].

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